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# Effect of gamma irradiation on the physico-mechanical and chemical properties of potato (*Solanum tuberosum* L.), cv. 'Kufri Sindhuri', in non-refrigerated storage conditions

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ABSTRACT

The effects of γ-irradiation doses, 0.04, 0.08, 0.12 and 1 kGy, applied at two different postharvest times (5 and 30 days after harvest), were studied on the textural behaviour (puncture force, shear force, work done to puncture and shear, cohesiveness and gumminess), microstructure, reducing sugar, total sugar and tuber losses of potato (*Solanum tuberosum* L.), cv. 'Kufri Sindhuri', during storage at 22 °C (RH: 85–90%). The lowest dose (0.04 kGy) was sufficient to inhibit sprouting in potatoes exposed on day 5 but not in the tubers exposed on day 30. The irradiated, non-sprouted potatoes maintained their appearance during storage. Potatoes irradiated early appeared more sensitive to radiation-induced damage, resulting in excessive loss of tubers at 1 kGy but low doses (up to 0.12 kGy) did not increase the susceptibility of the tubers to rotting. No significant differences between reducing sugar and total sugar contents of the control and low dose irradiated tubers were observed after 120 d. High dose (1 kGy) induced blackening of the bud tissue, increased rotting percentage and poor textural quality. Increasing low doses (up to 0.12 kGy) progressively reduced the textural deterioration in the tubers during storage. The scanning electron micrographs of potatoes irradiated with 0.08–0.12 kGy showed intact cells with rigid cell walls, accounting for the higher textural values registered by the samples. Among the two treatment timings, 'K. Sindhuri' irradiated early after harvest (i.e., on day 5) with 0.08–0.12 kGy doses retained higher textural parameters compared to those irradiated after a delay (day 30). The study showed the potential effect of γ-irradiation for enhancing the storage life of potatoes in non-refrigerated storage.



## 1. Introduction

Potato storage in tropical countries such as India is a major problem. The crop is harvested between January and March, after which the temperature rises, resulting in high physiological losses in stored tubers. Commonly used cold storage (2–4 °C) is very useful for long term storage of potatoes but renders them unsuitable for processing due to high accumulation of reducing sugars, and this is also a high energy consuming process for tropical countries. At the present time when conservation of energy has become important, potato storage at higher temperatures is a useful development, but requires application of sprout suppressants to maintain dormancy. The commonly used chemical sprout suppressants have raised concern regarding harmful residual effects (Kleinkopf et al., 2003). Moreover, refrigerated storage at 10–12 °C is also not fully developed in India. Non-refrigerated storage systems such as 'Evaporatively Cooled Storage' (ECS) (temperature: 20–25 °C, RH: 85–95%) for short term storage of potatoes, are very useful in reducing accumulation of reducing sugars, rotting and weight loss in the tubers (Mehta and Ezekiel, 2006).

Gamma (γ) irradiation is a safe and effective alternate sprout inhibiting method that allows potato tubers to be stored at higher temperatures. Low dose gamma irradiation (0.06–0.15 kGy) effectively inhibits sprouting in potato (Venugopal et al., 2002). Extending the storage life of potato at higher temperatures would be more economic and could play an important role in controlling the market price fluctuation of potatoes (Thomas, 2001). Food irradiation has versatile applications but has not been utilized to its full potential. However, the technique is steadily gaining worldwide acceptance and the number of gamma irradiation facilities is also increasing (EIR, 2008).

Ionizing radiations are high energy radiations, hence along with desirable effects, are also expected to produce certain undesirable changes by their interaction with different structural and chemical

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components of the tubers. A number of studies on the effect of γ-irradiation on various physico-chemical properties of potato have been carried out on different potato cultivars under different storage conditions for the evaluation of sprout inhibition, sugar content, ascorbic acid metabolism, chipping quality of the treated tubers, and properties of starch isolated from the treated tubers at lower doses (up to 0.5 kGy) (Frazier et al., 2006; Rana and Ezekiel, 2007; Ezekiel et al., 2008a,b; Kumar et al., 2009; Rezaee et al., 2011, 2013). Texture is another important quality parameter that determines the acceptability and shelf-life of fresh horticulture produce. It is primarily determined by the structural integrity of the cell wall and middle lamella as well as turgor pressure of the cells (Jackman and Stanely, 1995; Van Buggenhout et al., 2009). Insoluble starch granules stored in the tubers also play important role in potato texture (Singh et al., 2005).

Changes in the textural quality of raw potato reflect the changes in the structural elements as well as the physiological losses in the tuber during storage (Gao et al., 1989; Alvarez and Canet, 2000), hence, textural quality is an important parameter to monitor for tuber quality during storage. Increased physiological losses at higher storage temperatures reduce their storability to 2–3 months at 20 °C (Eltawil et al., 2006). A good postharvest technology should minimize storage losses and physico-chemical changes during storage. Therefore, the present study was carried out to understand the effect of gamma irradiation on the textural behaviour of potatoes (*Solanum tuberosum* L. cv. 'Kufri Sindhuri') stored in non-refrigerated conditions, and to evaluate its effectiveness in maintaining tuber qualities in terms of textural parameters, microstructure, sugar content and storage losses.

## 2. Materials and methods

### 2.1. Potato harvest and packaging

Potato '*Solanum tuberosum*' L. (Family: Solanaceae), cv. 'Kufri Sindhuri' was procured from the farms of Ranchi, Jharkhand. The tubers were harvested during January at full maturity after the dying of the haulms and adequate curing in soil. The potato tubers were packed in nylon bags and transported to Kolkata for irradiation. The potatoes were washed, air-dried and stored on the floor of a cool, airy, dry (20–22 °C) room till irradiation on days 5 and 30 after harvest. Throughout the study, the samples irradiated early (i.e., on day 5) were referred to as 'S-1', and the samples irradiated after a delay (i.e., on day 30) were referred to as 'S-2'.

For irradiation, equal sized potato tubers (45–50 g) of same days of maturity (postharvest timing) were packed separately in aerated low density polyethylene (LDPE) bags (thickness: 44 μm) measuring 21.5 cm × 15 cm. Holes were cut in the bags to facilitate gas exchange. Six bags each containing eight to ten potatoes were included at each dose. Six such bags were kept unirradiated as controls (0 kGy).

### 2.2. Gamma-irradiation

Gamma irradiation was carried out at the Food Irradiation Laboratory, NIL Campus, Jadavpur University, Kolkata using Co-60 gamma cell (Model: Gamma Chamber 5000, BARC, Mumbai) with a power source of 13.5 kCi and dose rate of 2.7 Gy/s during the study. 'K. Sindhuri' was irradiated with varying low doses of γ-ray (0.04 kGy, 0.08 kGy and 0.12 kGy) as well as at a higher dose (1 kGy).

### 2.3. Storage

The unirradiated and the irradiated potatoes were stored in a humidity cabinet (Prime Instruments) for 120 d at 22 ± 1 °C (RH: 85–90%). The physico-chemical and textural observations were made on days 0 and 120 of storage.

### 2.4. Sprout percentage

Tubers having at least one sprout of 0.5 cm length or more were recorded as sprouted (Mehta and Kaul, 2002) and the percentage of sprouting was calculated for each dose.

### 2.5. Rotting percentage

Any tuber showing a sign of soft rot or mould was considered as decayed. The percentage of rotting was calculated for each dose.

### 2.6. Total and reducing sugars

The reducing and total sugar contents of the unirradiated and irradiated samples were determined during storage by the dinitro salicylic acid (DNSA) method (Plummer, 2008). A calibration plot was drawn using a standard glucose solution in the range of 0–1.0 g $L^{-1}$. 10 g of peeled potato was cut and ground with a pestle and mortar. The homogenized paste was suspended in 20 mL of distilled water, filtered through a muslin cloth and centrifuged at 2516 × *g* for 15 min. The supernatant was used to determine the reducing sugars. For the estimation of total sugars, 200 μL of the supernatant was added to 800 μL of distilled water in a test tube and hydrolyzed with 172 μL of 12 N HCl at 68 °C for 8 min. The hydrolyzed sample after neutralization with 20% NaOH, was used for the determination of total sugars. OD was measured spectrophotometrically (Spectrophotometer U-1800, Hitachi) at 540 nm. The reducing sugars (mg/kg) on a fresh weight basis, and total sugar contents (mg/kg) on a fresh weight basis were calculated from the standard plot of glucose.

### 2.7. Textural analyses

Texture analyses of the unirradiated and irradiated tubers were done by puncture test, shear test and double compression test using an Instron Universal Testing Machine (Model 4301, Instron Ltd., UK).

#### 2.7.1. Puncture test

The whole potato tuber was placed on the base plate and punctured along its width from one end to another by a cylindrical puncture probe of 6 mm diameter driven through the potato from one end to the other at a crosshead speed of 0.25 mm/s under a working load of 100% of a 100 N load cell. The highest peak required to puncture through the flesh of the tuber was recorded in Newton (N), indicating tuber firmness. The work done (or toughness) to puncture the tuber was calculated as the area under the force-distance graph obtained, expressed in Newton metre (N m) (Rosenthal, 1999).

#### 2.7.2. Shear test

The whole potato tuber was placed on the base plate and cut through its cross section by a "V" shaped Warner – Bratzler Meat Shear Compressive type blade driven at the speed of 0.25 mm/s under a working load of 20% of the 1000 N load cell. The force–distance graphs obtained were compared by the peak force (N) required to shear through the flesh of the tuber. The work done (or toughness) to shear the potato was calculated as the area under the graph obtained, expressed in N m.

#### 2.7.3. Double compression test

A double compression test was performed using 50% working load of a 1000 N load cell on cylindrical samples (diameter

**Table 1**
Sprouting behaviour, rotting (%) and appearance of unirradiated and irradiated tubers of 'Kufri Sindhuri'[a] stored for 120 d at 22 °C.

| Dose (kGy) | Sprout (%) | Max. spr. length (cm) | Rotting (%) | Appearance |
|---|---|---|---|---|
| *Kufri Sindhuri (S-1)* | | | | |
| 0.00 | 100 | 2.5 ± 0.5 | 2.00 | SS |
| 0.04 | 00 | 0.0 | 8.00 | F |
| 0.08 | 00 | 0.0 | 4.00 | F |
| 0.12 | 00 | 0.0 | 4.00 | F |
| 1.00 | 00 | 0.0 | 42.00 | Spoiled |
| *Kufri Sindhuri (S-1)* | | | | |
| 0.00 | 100 | 3.1 ± 0.4 | 11.1 | S |
| 0.04 | 10 | 1.1 ± 0.4 | 5.6 | S |
| 0.08 | 00 | 0.0 | 7.4 | SS |
| 0.12 | 00 | 0.0 | 7.4 | F |
| 1.00 | 00 | 0.0 | 7.4 | SS |

S, shrivelled; SS, slightly shrivelled; F, firm; dos, days of storage.
[a] S-1: irradiated 5 d after harvest, S-2: irradiated 30 d after harvest.

2.5 cm × 1 cm) that were compressed (25% compression) on a non-lubricated platform using a flat disc probe of 40 mm diameter, moving at a speed of 0.25 mm/s. Cohesiveness and gumminess were determined from the texture profile analysis (TPA) graphs following Bourne (1978). Cohesiveness is expressed as the dimensionless quotient of the areas represented by the work to be done for two bites. Gumminess is defined as the product of hardness and cohesiveness.

$$\text{Cohesiveness}: \frac{\text{Area of the graph obtained during second compression} \quad (\text{N m})}{\text{Area of the graph obtained during first compression} \quad (\text{N m})}$$

$$\text{Gumminess} \quad (\text{N}): \text{Hardness} \quad (\text{N}) \times \text{Cohesiveness}$$

### 2.8. Scanning electron microscopy

Scanning electron microscopy of the potato samples was carried out after 60 d of storage. Small, thin sections of potato tissue were cut from the whole potato using sharp blade and dehydrated using a freeze Ddyer (Eyela, FDU 1200). Samples thus prepared, were viewed in a scanning electron microscope (SEM) with magnification of 200×.

### 2.9. Statistical analysis

The physico-chemical determinations of unirradiated and irradiated potato tubers were made in 3 replications. The data were subjected to Duncan's Multiple Range Test (DMRT) following Gacula and Singh (1984), and statistical significance was tested at $p \leq 0.05$.

## 3. Results

### 3.1. Sprouting behaviour, tuber appearance and storage losses

The lowest dose studied, 0.04 kGy, successfully inhibited sprouting, when tubers were irradiated on day 5 of harvest (S-1) (Table 1, Fig. 1), but not in the tubers irradiated on day 30 (S-2) (Table 1, Fig. 2). Higher doses successfully inhibited sprouting of the potatoes irrespective of the treatment timing. Excessive shrivelling occurred in the unirradiated control tubers. Although deterioration in appearance occurred during storage, potatoes irradiated on day 5 with 0.04–0.12 kGy and on day 30 with 0.08 and 0.12 kGy, maintained a firm appearance even after 120 d at 22 °C. Exposure with 1 kGy resulted in blackening of the bud tissue. Irradiation with lower doses did not markedly increase the rotting percentage, however, a slight increase compared to the unirradiated controls was recorded when the tubers were irradiated early, i.e., on day 5. Irradiation on day 30 greatly restricted the rotting percentage both at low and high doses (Table 1).

### 3.2. Reducing and total sugars

The effect of gamma irradiation on the reducing sugar contents of tubers (S-1: irradiated 5 d after harvest; S-2: irradiated 30 d after harvest) during storage at 22 °C is shown in Fig. 3. The initial reducing sugar contents of fresh harvested control 'S-1' was $1.5 \times 10^3$ mg/kg while that of 'S-2' control was $2.2 \times 10^3$ mg/kg. No immediate effect of irradiation was observed at low doses, but exposure with the high dose (1 kGy) showed a tendency to increase the reducing sugar contents. Similarly, an increase in total sugar contents was also recorded at 1 kGy (Fig. 4). Both unirradiated and irradiated tubers accumulated sugars during storage, however, there was

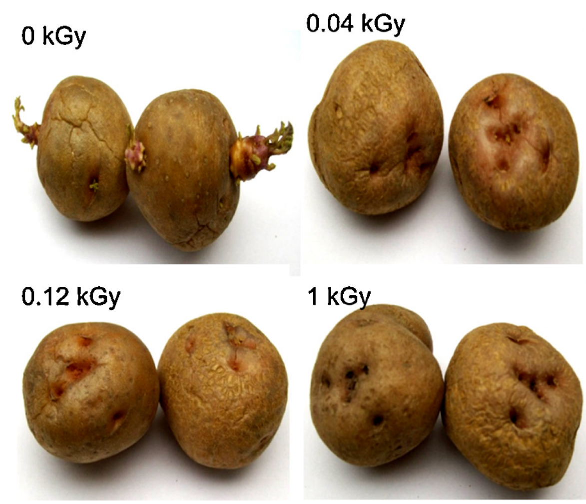


**Fig. 1.** Unirradiated and irradiated 'Kufri Sindhuri' tubers (S-1: irradiated 5 d after harvest) and stored for 120 days at 22 °C.

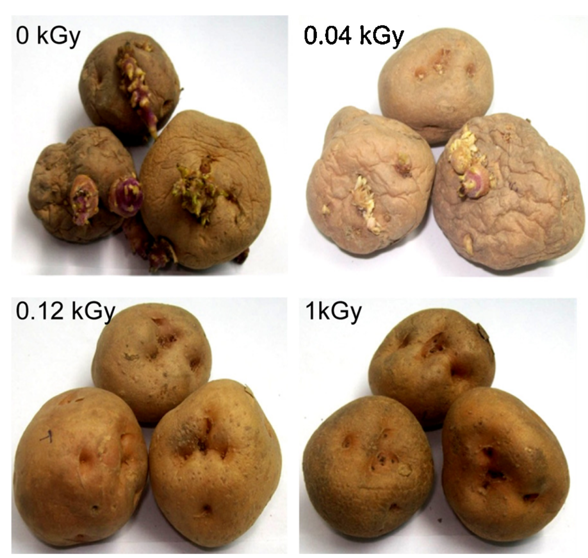


**Fig. 2.** Unirradiated and irradiated 'Kufri Sindhuri' tubers (S-2: irradiated 30 d after harvest) and stored for 120 days at 22 °C.

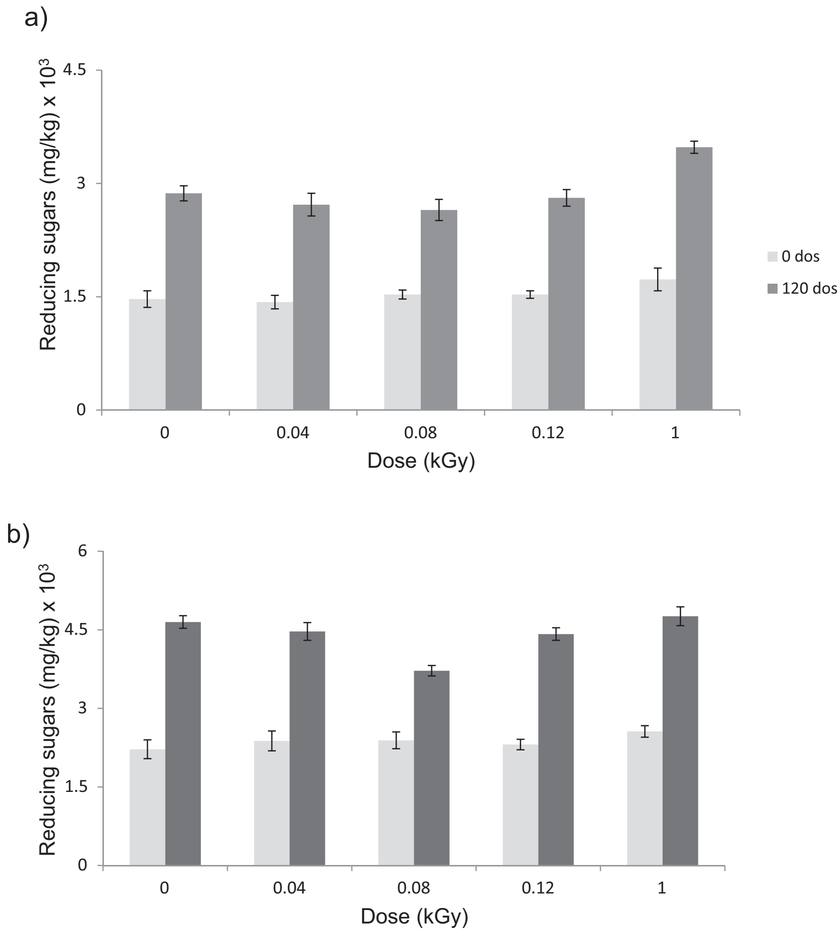


**Fig. 3.** Effect of γ-irradiation on the reducing sugar contents (mg/kg fresh weight) of 'Kufri Sindhuri' tubers during storage of 120 days at 22 °C. (a) S-1: irradiated 5 d after harvest, (b) S-2: irradiated 30 d after harvest.

no significant difference between the control and the low dose irradiated tubers after 120 d, except 'S-2' irradiated with 0.12 kGy which showed significantly higher total sugar contents. The reducing sugars and total sugars of the samples treated with 1 kGy remained significantly higher after 120 d. The unirradiated as well as the irradiated potatoes of 'S-1' showed less accumulated sugars after 120 d compared to those of 'S-2'.

### 3.3. Textural analyses

#### 3.3.1. Puncture test

Effect of gamma irradiation on the puncture force of unirradiated and irradiated potatoes during 120 d storage is shown in Fig. 5. The average peak force required to puncture the unirradiated and low dose (up to 0.12 kGy) treated 'S-1' potatoes ranged between 40 and 45 N, while for 'S-2' this ranged between 45 and 50 N. No adverse effect of gamma rays was observed at low doses, but puncture force was reduced considerably at 1 kGy and remained so throughout storage. Analyzing the textural change of 'S-1' during storage showed a sharp decrease of puncture force in the unirradiated control (35%) as well as in the samples treated with 0.04 kGy (8%), over 120 d. The tubers exposed to 0.08 and 0.12 kGy retained their puncture force throughout the storage period. The samples also retained their toughness and no deterioration was observed in work done required to puncture the tubers (Fig. 6). In comparison, 'S-2' registered a decrease in puncture force by 57%, 40%, 21% and 14% at 0 kGy, 0.04 kGy, 0.08 kGy and 0.12 kGy respectively, during 120 d storage. The work done to puncture the tubers also decreased by 47%, 45%, 36% and 18% at 0 kGy, 0.04 kGy, 0.08 kGy and 0.12 kGy, respectively.

After 120 d, samples of both 'S-1' and 'S-2' irradiated with doses 0.08 and 0.12 kGy were significantly ($p \leq 0.05$) firmer and tougher compared to their controls. Comparison between the treatment timing showed that potatoes irradiated early after harvest (S-1) were firmer and tougher compared to those irradiated after a delay (S-2).

#### 3.3.2. Shear test

The shear test also revealed similar trends between unirradiated and irradiated specimens of both 'S-1' and 'S-2' as observed in the puncture test (Supplementary Figs. 1 and 2).

#### 3.3.3. Cohesiveness and gumminess

The initial cohesiveness of unirradiated and low dose irradiated potatoes (S-1 and S-2) ranged between 0.75 and 0.8 (Fig. 7). The initial gumminess of unirradiated and low dose irradiated 'S-1' ranged between 325 and 355 N while those of 'S-2' ranged between 303 and 307 N (Fig. 8). Consistent with the puncture and shear tests, no immediate effect of irradiation was observed at low doses, but a noticeable reduction (9–20%) in both cohesiveness and gumminess was recorded at 1 kGy. During storage of 120 d, 'S-1' irradiated with doses 0.04, 0.08 and 0.12 kGy showed a reduction in cohesiveness by 15%, 14%, 14% and 13%, while gumminess was reduced by 34%, 25%, 14% and 3%, respectively. In comparison, 'S-2' irradiated with doses 0.04, 0.08 and 0.12 kGy registered a decrease in cohesiveness by 29%, 27%, 21% and 20% while the gumminess was reduced by 39%, 28%, 15% and 11%, respectively.

### 3.4. Microstructure

The scanning electron micrographs of the potato samples showed hexagonal cells (~100 μm × 150 μm) cut open, revealing the starch granules (Figs. 9 and 10). The low dose irradiated specimens showed rigid cell walls while the sample exposed to the higher dose (1 kGy), particularly the specimen exposed early (on day 5) showed more collapsed cells with less rigid cell walls.

## 4. Discussion

Loss of moisture and sprouting are important reasons for deterioration in appearance of stored potatoes at a high storage temperature; however, the low dose irradiated tubers maintained a firm appearance for 120 d. Irradiation successfully inhibited sprouting, and thereby the changes associated with sprouting, but with a delay in treatment timing, higher doses were required for effective sprout inhibition, as also reported by Rezaee et al. (2011, 2013). Irradiation is known to impair wound periderm formation, resulting in increased loss of tubers by rotting (Thomas, 1982; Ghanekar

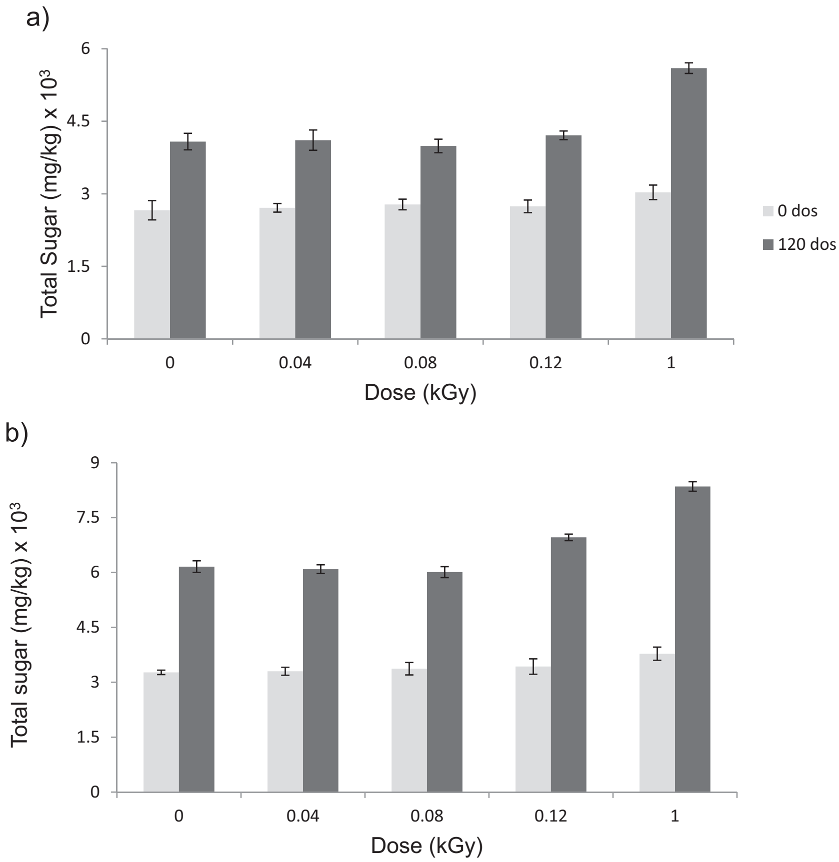


**Fig. 4.** Effect of γ-irradiation on the total sugar contents (mg/kg fresh weight) of 'Kufri Sindhuri' tubers during storage of 120 days at 22 °C. (a) S-1: irradiated 5 d after harvest, (b) S-2: irradiated 30 d after harvest.

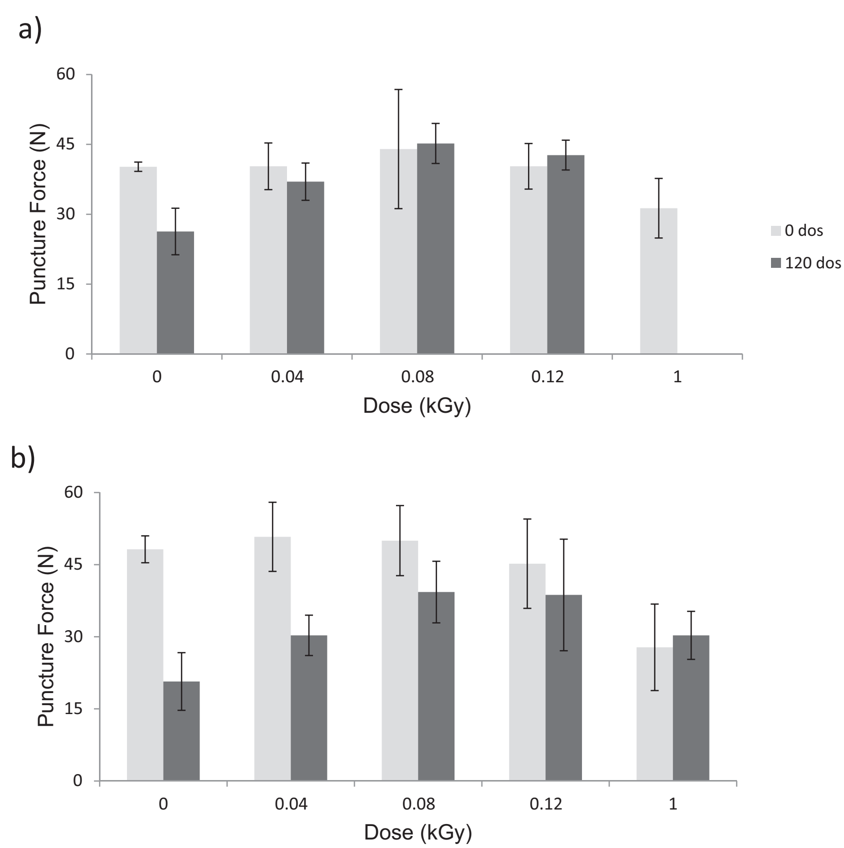


**Fig. 5.** Effect of γ-irradiation on the puncture force (N) of 'Kufri Sindhuri' tubers during storage of 120 days at 22 °C. (a) S-1: irradiated 5 d after harvest, (b) S-2: irradiated 30 d after harvest.

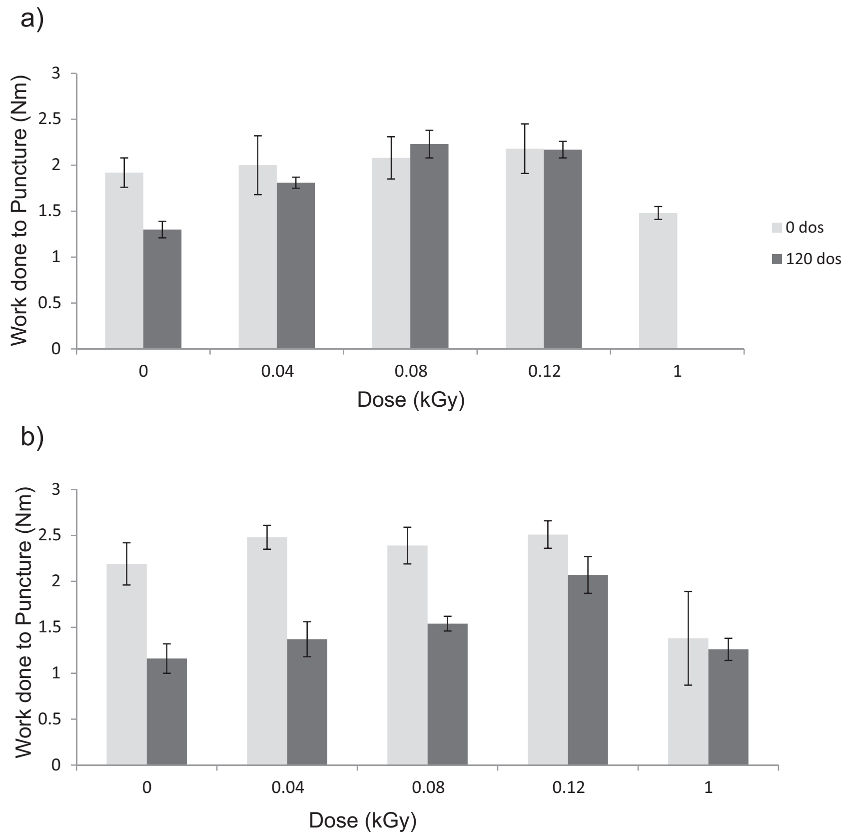


**Fig. 6.** Effect of γ-irradiation on the 'work done' (N m) to puncture 'Kufri Sindhuri' tubers during storage of 120 days at 22 °C. (a) S-1: irradiated 5 d after harvest, (b) S-2: irradiated 30 d after harvest.

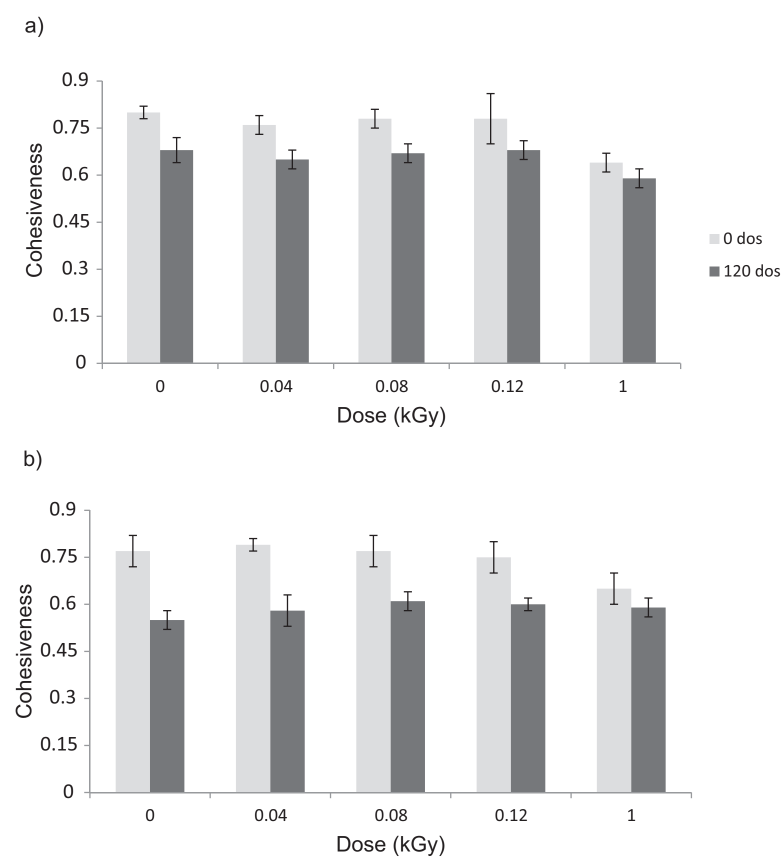


**Fig. 7.** Effect of γ-irradiation on the cohesiveness of 'Kufri Sindhuri' tubers during storage of 120 days at 22 °C. (a) S-1: irradiated 5 d after harvest, (b) S-2: irradiated 30 d after harvest.

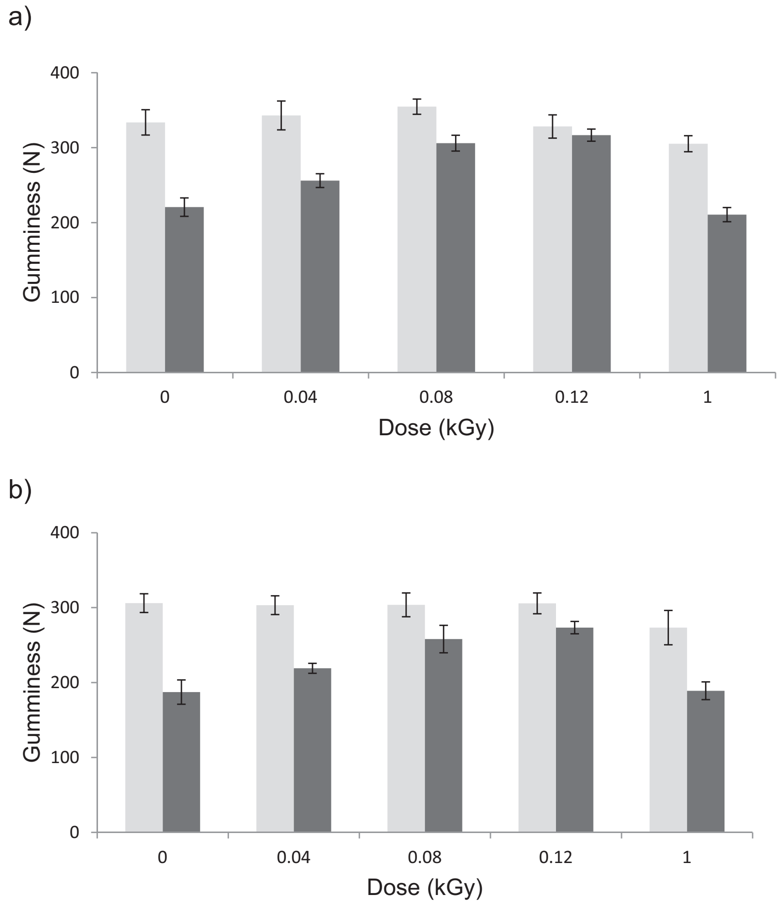


**Fig. 8.** Effect of γ-irradiation on the gumminess of 'Kufri Sindhuri' tubers during storage of 120 days at 22 °C. (a) S-1: irradiated 5 d after harvest, (b) S-2: irradiated 30 d after harvest.

et al., 1983). The immature skin of potatoes irradiated early (i.e., on day 5) appeared more sensitive to radiation-induced damage, leading to excessive loss of tubers at 1 kGy. However, the lower doses (up to 0.12 kGy) did not enhance the susceptibility of the tubers to rotting, even during high temperature storage. The blackening of the bud tissue on exposure to a high dose (1 kGy) suggested cell death. Being meristematic and metabolically active, the bud tissue is particularly sensitive to irradiation.

Although sugars occur in small amounts, they play an important part in potato flavour and are of considerable importance

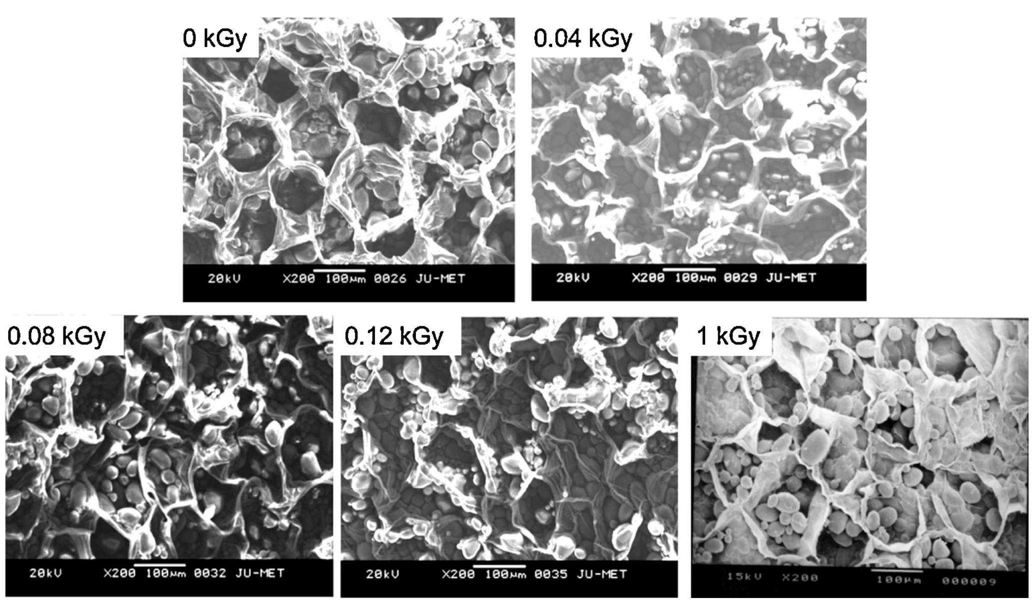


**Fig. 9.** Scanning electron micrographs of the flesh part of unirradiated and irradiated 'Kufri Sindhuri' tubers (S-1: irradiated 5 d after harvest).

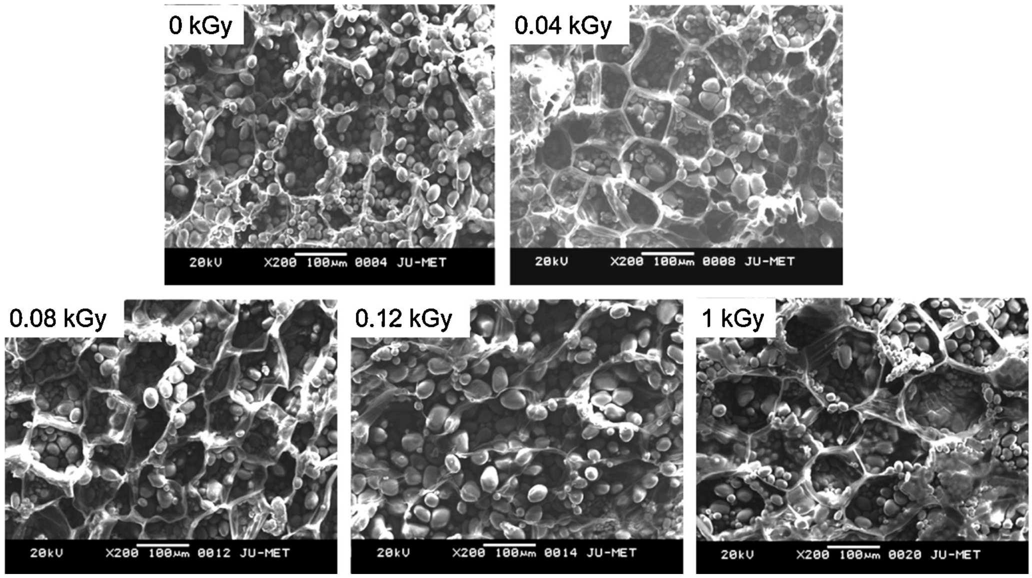


**Fig. 10.** Scanning electron micrographs of the flesh part of unirradiated and irradiated 'Kufri Sindhuri' tubers (S-2: irradiated 30 d after harvest).

in the colour of the processed products (Woolfe, 1987). Irradiation induces a temporary rise in the sugar content of the tubers (Burton, 1975). A number of authors have reported that with sprout inhibition, the increased sugar content of the low dose irradiated samples became less significant compared to that of the unirradiated controls during prolonged storage (Frazier et al., 2006; Mulla et al., 2011). Similarly, no significant difference between the sugar content of the unirradiated and low dose treated potatoes was observed after storage of 120 d. 'Kufri Sindhuri' tubers irradiated on day 5 of harvest showed less accumulated reducing and total sugars compared to the samples irradiated after a delay, which might be related to the initial low sugar content of the freshly harvested potatoes. However, less accumulated sugars is desirable, as it would maintain the good taste of the tubers.

Both puncture and shear tests have been reported for measuring textural changes in raw potatoes (Abu-Ghannam and Crowley, 2006). The peak forces indicate tuber firmness, while the work done or toughness is a measure of energy required to deform the tuber and is a measure of its mechanical strength. As mentioned earlier, a number of factors, such as structural components of the cell wall and middle lamella, turgidity of the cells and starch content are responsible for the textural characteristics of potatoes. Although no immediate effect of low dose irradiation was observed on different textural parameters of raw potatoes, the plant tissue was particularly sensitive to irradiation damage at the higher dose (1 kGy). The significant reduction in tuber firmness and toughness at 1 kGy indicated reduction in resistance of the tuber to mechanical deformation, which might be due to radiation-induced degradation of the structural components of the tuber. Cohesiveness is a measure of internal bonding of the material, thus, decrease in cohesiveness further supported breakage of bonds in the structural polysaccharides of the tuber. The observation was in accordance with results from Echandi et al. (1970) and d'Amour et al. (1993), who reported random cleavages in the glycosidic bonds between the cellulose and polygalacturonic acid chains of the cell walls, resulting in the degradation of pectin and cellulose component of the cell walls at and above 1 kGy. The less rigid cell walls observed in the scanning electron micrograph of the specimens irradiated with 1 kGy also support the observation.

Storage at a high temperature (22 °C) increases physiological losses from the tuber due to higher rate of respiration and evaporation of water as well as increased breakdown of starch induced by sprouting (Eltawil et al., 2006), resulting in the deterioration of the textural quality of the stored tubers, reflected in the reduction of the peak forces obtained by puncture and shear tests during storage. Decreased cohesiveness and gumminess indicated increased cell wall damage during high temperature storage (Burton, 1989). The control tubers were significantly ($p \leq 0.05$) less firm. However, exposure with increasing doses of γ-rays (up to 0.12 kGy), progressively decreased the textural loss of the tubers during storage. Irrespective of the treatment timing, tubers exposed to 0.08 and 0.12 kGy retained their textural characteristics better throughout the storage period compared to those irradiated with 0.04 kGy. The observation was in accordance with those of Mahboob et al. (2004) and Rezaee et al. (2011, 2013), who reported reduced loss of starch and tuber weight at 0.075–0.15 kGy compared to that at 0.05 kGy. According to Mahboob et al. (2004), irradiation restricted the metabolic rate of the potato. Thus, it appeared that greater restriction of the metabolic activities of the tubers at 0.08–0.12 kGy preserved the textural characteristics better compared to the sample irradiated with 0.04 kGy.

Of the two postharvest treatment timing studied, tubers exposed on day 5 (i.e., S-1) showed a slower rate of decrease in puncture strength, cohesiveness and gumminess and retained higher textural parameters compared to those irradiated on day 30 (i.e., S-2). It was noticeable that 'S-1' irradiated with 0.08 and 0.12 kGy showed no deterioration in puncture strength throughout the storage period of 120 d. The radiation-induced sprout inhibition is probably a result of DNA damage, causing reduction in the biosynthesis of plant growth hormones and enzymes, interfering with the normal metabolism of the tuber (Diehl, 1995). The tubers exposed to gamma treatment early after harvest are more sensitive to irradiation due to their more active metabolic state (IAEA, 1982), thus early irradiation would induce greater restriction of their normal metabolism, which might have preserved their physico-chemical parameters better.

## 5. Conclusion

The study showed the potential of γ irradiation to be developed as an effective postharvest technique for storage of potatoes in non-refrigerated conditions such as ECS. The treatment timing was observed to be an important factor. Early irradiation with low doses

(0.08-0.12 kGy) could effectively maintain the physico-mechanical properties of potatoes during storage at 22 °C for 120 d, thereby, extending the shelf-life of the stored potatoes.

## Acknowledgements

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.postharvbio.2014.01.011.

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